AD-754 213

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Illinois University

Prepared for:

Air Force Office of Scientific Research

May 1972

DISTRIBUTED BY:

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National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

Technical Report ARL-72-9/AFOSR-72-4
May 1972

Research supported by:

Air Force Office of Scientific Research
Contract F44620-70-C-0105

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Prepared for:
Life Sciences Program
Air Force Office of Scientific Research

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R25

UNCLASSIFIED

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Aviation Research Laboratory, Institute of Aviation University of Illinois Urbana, Illinois 61801	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP
3. REPORT TITLE THE INCREMENTAL TRANSFER EFFECTIVENESS OF A GROUND-BASED GENERAL AVIATION TRAINER	
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Scientific Interim	
5. AUTHOR(S) (First name, middle initial, last name) H. Kingsley Povenmire and Stanley N. Roscoe	
6. REPORT DATE May 1972	7a. TOTAL NO. OF PAGES ~~20~~ 25 7b. NO. OF REFS 9
8a. CONTRACT OR GRANT NO. F44620-70-C-0105 b. PROJECT NO. 9778 c. 61102F d. 681313	9a. ORIGINATOR'S REPORT NUMBER(S) 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) AFOSR - TR - 72 - 2466
10. DISTRIBUTION STATEMENT Approved for public release; distribution unlimited.	
11. SUPPLEMENTARY NOTES TECH, OTHER	12. SPONSORING MILITARY ACTIVITY Air Force Office of Scientific Research 1400 Wilson Boulevard (NL) Arlington, Virginia 22209
13. ABSTRACT	

-i-

DD FORM 1 NOV 65 1473

UNCLASSIFIED

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Incremental Transfer Effectiveness						
Ground-Based General Aviation Trainer						
Cost Effectiveness						

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The Incremental Transfer Effectiveness of a Ground-Based General Aviation Trainer

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Link trainers and similar synthetic flight training devices have been used with varying effectiveness since before World War II. Currently available ground-based flight trainers differ widely in their degree and fidelity of simulation and in their associated costs. To provide a rational basis for trainer procurement, a method of assessing their cost effectiveness is needed.

An experiment was conducted to establish the Incremental Transfer Effectiveness of a representative ground-based general aviation trainer to serve as a basis for the evaluation of its incremental cost effectiveness. Four groups of student pilots were given, respectively, 0, 3, 7, and 11 hours of instruction in the Link GAT-1 concurrently with flight instruction in the Piper Cherokee airplane. Average flight times for the four groups to reach the Private Pilot criterion reflected the postulated negatively decelerated nature of the Incremental Transfer Effectiveness Function.

BACKGROUND

Almost a quarter of a century ago, Williams and Flexman (1949) put forth the important notion that ground-based flight trainers, or flight simulators as we know them today, should be evaluated in terms of their "training efficiency." Five years later, Williams and Adelson (1954) suggested a mathematical model for assessing the utility of increasingly complex and faithful simulation devices in terms of their training-cost efficiency. In the summer of 1969, Povenmire and Roscoe (1971) conducted an experiment that allowed the transfer of training from the old AN-T-18 and the new GAT-1 Link trainers to the Piper Cherokee airplane to be expressed in terms of their relative "transfer effectiveness." Soon thereafter, Roscoe (1971) distinguished between "incremental" and "cumulative" transfer effectiveness, and Flexman, Roscoe, Williams, and Williges (1972) reported in similar terms the detailed results of two previously unpublished experiments conducted in 1950.

The importance of the transfer effectiveness notion lies in the fact that it provides a basis for an objective assessment of the cost effectiveness of any training device or program in incremental terms. The Incremental Transfer Effectiveness Function (ITEF) answers the question of how much time is saved in one training situation as a consequence of each successive increment of training in another, generally less costly, situation.

Although the ITEF may be expected to assume a negatively decelerated form (Roscoe, 1971; 1972), its parameters may vary widely from task to task, course to course, and curriculum to curriculum. The present experiment was designed to determine the relationship between successive increments of ground-based training in the Link GAT-1 and the corresponding incremental savings in flight training in the Piper Cherokee required to reach Private Pilot proficiency in a routine pilot training program.

EXPERIMENT

During the fall semester of 1971-72, students with no previous flight instruction enrolled in the Private Pilot course (Aviation 101) at the Institute of Aviation, University of Illinois at Urbana-Champaign, received varying amounts of training in the Link GAT-1 (Figure 1) concurrently with their flight training in the Piper Cherokee PA-28-140B (Figure 2). A control group and three transfer groups received 0, 3, 7, and 11 hours, respectively, in the GAT-1 and sufficient time in the Cherokee to complete their flight training. Students from each of the six daily flight periods were randomly assigned to experimental groups and to flight instructors.

Completion of flight training occurs when one of three criteria is met: (1) passage of a final flight check, (2) completion of a maximum of 50 hours of combined flight and ground training without having passed a final flight check, or (3) completion of a maximum of 31.3 hours of dual flight instruction without having soloed. Students may also withdraw from flight training voluntarily. All students who pass the ground school portion of Aviation 101 are considered to have completed the course, regardless of the outcome of flight training. Estimates of transfer effectiveness of the GAT-1 were based upon the relative amounts of flight training required by those students in the various experimental groups who were recommended for certification as Private Pilots.

Procedure

Flight instructors were allowed to use the GAT-1 as they chose, both with respect to the distribution of the training time allowed members of each transfer group and to the items selected for practice from the full 11-hour ground training syllabus normally covered in the Institute's established training program. This syllabus places initial emphasis on basic aircraft control by reference to instruments, then on traffic pattern procedures, followed by training on precise heading and altitude control, emergency procedures, and cross-country flying including VOR navigation.

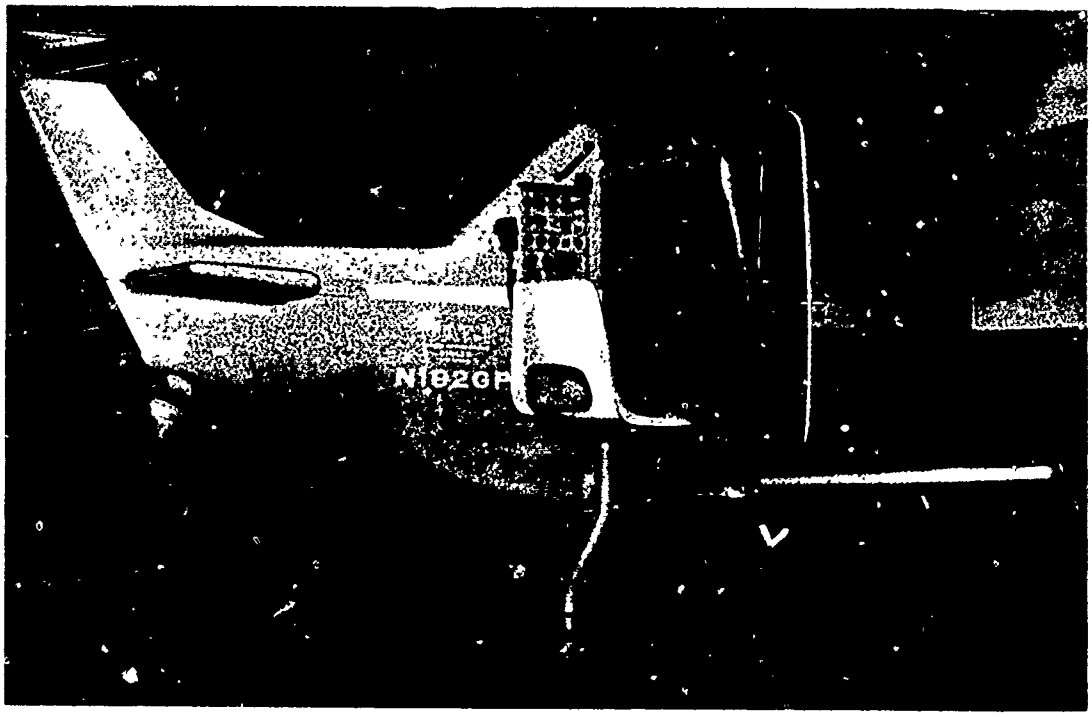

Figure 1. The Link GAT-1 general aviation trainer.

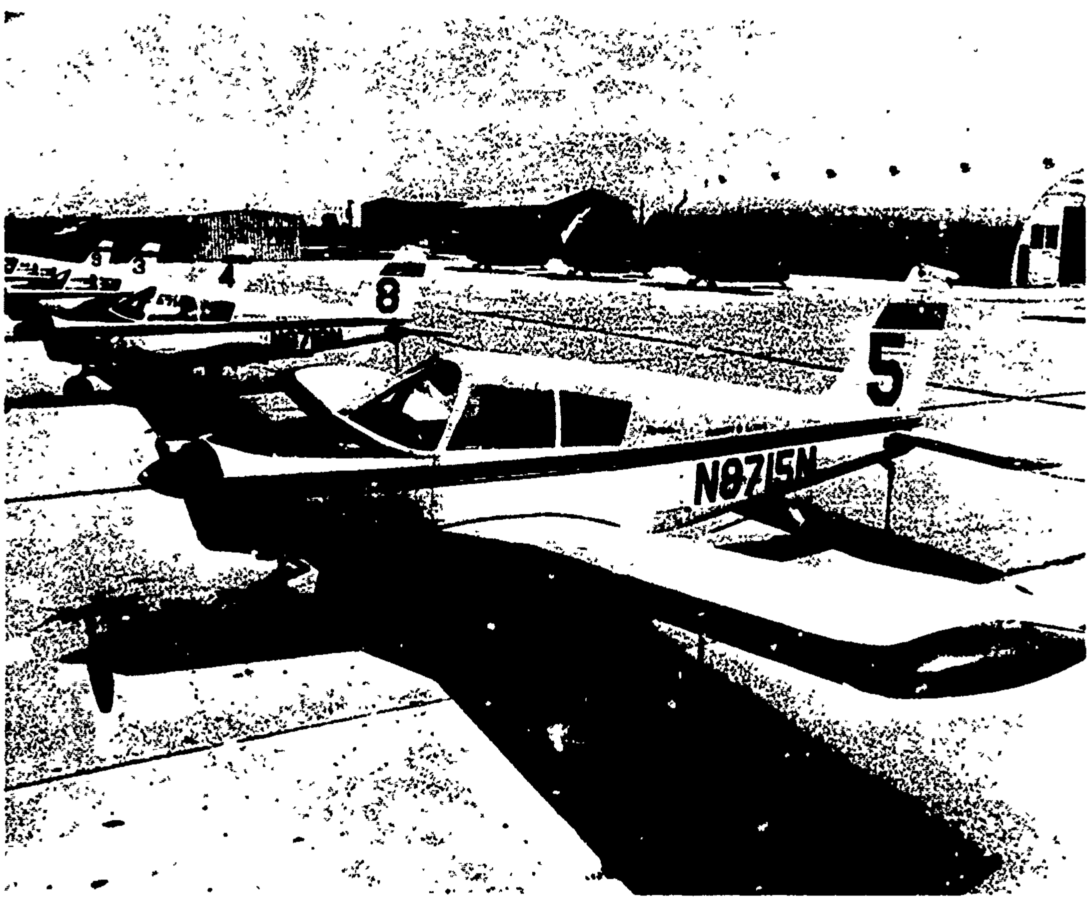

Figure 2. The Piper Cherokee PA-28-140B primary flight trainer.

Except for the variable amounts of ground training allowed for the different groups, the structure and conduct of the normal Private Pilot flight course were closely followed to obtain generalizable results. Nevertheless, because the routine training of pilots at the Institute of Aviation has, itself, become the object of systematic experimental investigation during recent years, certain practices commonly followed are not typical of other established pilot training programs.

Specifically, subjects were given flight checks after each ten-hour increment of training in the aircraft and another flight check if needed prior to recommendation for the final flight check. On all flight checks prior to the final check by an authorized flight examiner, a student was rated independently by his instructor in the right front seat and by a second flight instructor-observer in the right rear seat of the Cherokee.

The Illinois Private Pilot Performance Scale, which evaluates performance on each of ten flight maneuvers from the FAA's Private Pilot flight test guide, was used as the rating instrument (Povenmire, Alvares, and Damos, 1970). Four to six quantitative variables for each maneuver are scored by marking the maximum deviation from desired performance on an appropriate scale. Observer-observer reliability in excess of .80 has been found for this instrument (McGrath and Harris, 1971; Selzer, Hulin, Alvares, Swartzendruber, and Roscoe, 1972).

Students who failed to be recommended for certification by their instructors were eliminated from consideration in the assessment of transfer for the various experimental groups. Of the 200 or more students who annually take the Aviation 101 course at the Institute of Aviation, between 20 and 25 percent are not recommended for certification regardless of the amount of flight and ground instruction they receive. Generally students not recommended are ones who have not soloed after receiving all or most of the maximum of 31.3 hours of dual instruction. Rarely do students complete the maximum of 50 hours of combined dual and solo flight and ground training without being recommended for a final flight check, and none did so in this experiment. In fact, because of the nature of the experiment, three students in the control group, who were denied any training in the GAT-1, were allowed to

exceed the 50-hour maximum by 0.8, 1.2, and 3.7 hours, respectively, upon the recommendations of their instructors, and all passed.

Although the FAA imposes a minimum experience requirement for the Private Pilot Certificate, instructors were asked to schedule a student's final flight check as soon as the student could be expected to pass on the basis of his normal performance. If the student passed prior to completing the minimum required flight time, his training was continued beyond the successful flight check until FAA requirements were met.

Performance Measurement

Transfer of training assessments were based upon savings in flight time measured in two ways: the time at which a student passed the final flight check and the time at which a student's learning curve passed through a criterion level approximating that required to pass the final check. Although these two measures are positively correlated, they are not identical and, under certain circumstances, can differ substantially.

The time at which a student takes and passes his final flight check in a highly structured training program is constrained in a number of subtle ways even in an experimental situation. Although a student may be recommended for his final check at any time, in practice a minimum of about 25 hours is required to introduce the student to all procedures and maneuvers upon which he will be tested no matter how rapidly he can assimilate the material presented.

Conversely, students who learn more slowly, though surely, will be recommended and will pass their final flight checks when the semester ends, even though they may lack the degree of precision readily demonstrated by faster learners with fewer flight hours. Thus, the variability in time to pass the final flight check is artificially constrained in a structured training situation with unyielding calendar limitations.

To obtain a more objective basis for evaluating terminal proficiency, a least-squares straight-line learning curve was fitted to flight check scores each student received on the Illinois Private Pilot Peformance Scale throughout training.

This procedure yielded a less constrained estimate of the point at which each student's proficiency passed through a criterion level approximating the performance required barely to pass the final flight check.

The scoring of the Illinois Private Pilot Performance Scale was designed arbitrarily to give equal weighting to each of the variables measured on all ten maneuvers. Scores by both the instructors and the observers for all flight checks immediately preceding recommendations for final checks were pooled for each variable measured, and standard deviations were calculated. Individual deviations from optimum values established in advance by the flight instructors were divided by the standard deviations of their respective distributions of scores on the recommendation checks to provide a modified $\underline{z}$ score. Mean $\underline{z}$ scores were then calculated for each student's 10-hour, 20-hour, 30-hour, and final flight checks, and the straight line best fitting these four points was calculated for each student.

The average standard score for all students in all groups on their successful final checks was used as the criterion of Private Pilot proficiency. This value happened to fall at 0.97 and, for convenience, was rounded off to 1.0. The point at which each student's learning curve crossed the standard-score criterion of 1.0 was calculated, the resulting flight times were averaged for each group, and the various measures of transfer were based on these group means.

RESULTS

Success Ratios

Table 1 shows the disposition of all students who completed flight training including 65 in the four experimental groups and 20 with some prior flight training who were not included in the experiment. These nonexperimental students received the normal quota of 11 hours of training in the GAT-1 and the remainder of their training in flight. Not included in Table 1 were two students who withdrew from the course (one of whom had been assigned to the control group and one to the 7-hour transfer group), and three students (two from the control group and one from the

7-hour group) who failed the ground school portion of the Aviation 101 course prior to completing flight training and were therefore automatically eliminated from further consideration.

The final flight check passing ratios for the control group and for the three transfer groups combined were virtually identical, 70 percent versus 71 percent. Although the passing ratios for the three transfer groups ranged from 59 percent for the group that received 11 hours in the GAT-1 to 93 percent for the group that received three hours, a Chi-square test (for whatever it may be worth with such small frequencies) indicated that the differences in success ratios among all four groups would be expected to occur almost 50 times in 100 by chance.

A more unusual result was the success rate of 85 percent for the nonexperimental students who had varying amounts of previous flight training. Typically these students are less successful as a group in the Aviation 101 course than beginning students. Finally, the overall success rate of 74 percent (excluding the students that withdrew and those that failed the ground school course) was at the lower end of the range encountered at the Institute of Aviation.

Transfer Effects

Flight times at which all successful experimental students passed their final flight checks and a summary of the transfer measures based thereon are presented in Table 2. The corresponding values for the times at which students reached the $\underline{z}$-score Private Pilot performance criterion of 1.0 are given in Table 3. Cumulative and Incremental Transfer Effectiveness Functions for each measure are graphed in Figure 3.

Average flight times at which the four groups passed their flight checks differed orderly and reliably ($\underline{p}$ = 0.0014) as indicated in the summary of the analysis of variance for independent groups with unequal Ns shown in Table 4. The average time at which the various groups reached the $\underline{z}$-score criterion closely

TABLE 2

Flight Times in Hours to Pass Final Flight Check and Summary of Resulting Transfer Measures

Hours in GAT-1	CONTROL GROUP 0	TRANSFER GROUPS 3	7	11
Hours in Cherokee	41.3	44.8	42.7	37.3
	45.6	44.8	37.1	37.5
	48.0	47.5	40.2	40.7
	49.0	44.3	43.3	39.6
	46.0	40.6	42.5	34.8
	43.3	25.6	42.8	35.8
	43.7	32.4	35.8	40.1
	53.7	43.2	35.0	37.1
	41.2	36.8	28.2	34.8
	41.6	39.3		41.6
	51.2	39.0		
	38.0	40.1		
	50.8	45.0		
	42.5			
N	14	13	9	10
$\bar{X}$	45.42	40.26	38.62	37.93
σ	4.51	6.00	5.07	2.45
Cumulative Savings		5.16	6.80	7.49
Incremental Savings		5.16	1.64	0.69
CTER		1.72	0.97	0.68
ITER		1.72	0.41	0.17
% Transfer		11	15	16

TABLE 1

Disposition of All Students Who Completed Flight Training

Group	Total	Passed	Failed	% Passed
Control	20	14	6	70
3 Hours in GAT-1	14	13	1	93
7 Hours in GAT-1	14	9	5	64
11 Hours in GAT-1	17	10	7	59
	65	46	19	71
Nonexperimental	20	17	3	85
All Students	85	63	22	74

TABLE 3

Flight Times in Hours to Reach Proficiency Criterion and Summary of Resulting Transfer Measures

Hours in GAT-1	CONTROL GROUP	TRANSFER GROUPS		
	0	3	7	11
Hours in Cherokee	29.54	47.59	33.78	35.62
	47.23	39.88	41.52	30.55
	42.64	60.00	41.94	43.76
	42.26	*	38.88	34.45
	37.71	45.54	57.74	33.99
	34.32	23.56	47.56	28.93
	45.46	25.74	37.70	34.46
	40.48	38.82	25.87	59.27
	50.40	41.54	19.46	32.33
	46.15	38.65		39.61
	52.24	34.48		
	39.41	36.75		
	70.56	46.29		
	44.50			
N	14	12	9	10
$\bar{X}$	44.49	39.90	38.27	37.30
σ	9.64	9.76	11.28	8.82
Cumulative Savings		4.59	6.22	7.19
Incremental Savings		4.59	1.63	0.97
CTER		1.53	0.89	0.65
ITER		1.53	0.41	0.24
% Transfer		10	14	16

* Barely failed to reach proficiency criterion but passed final flight check.

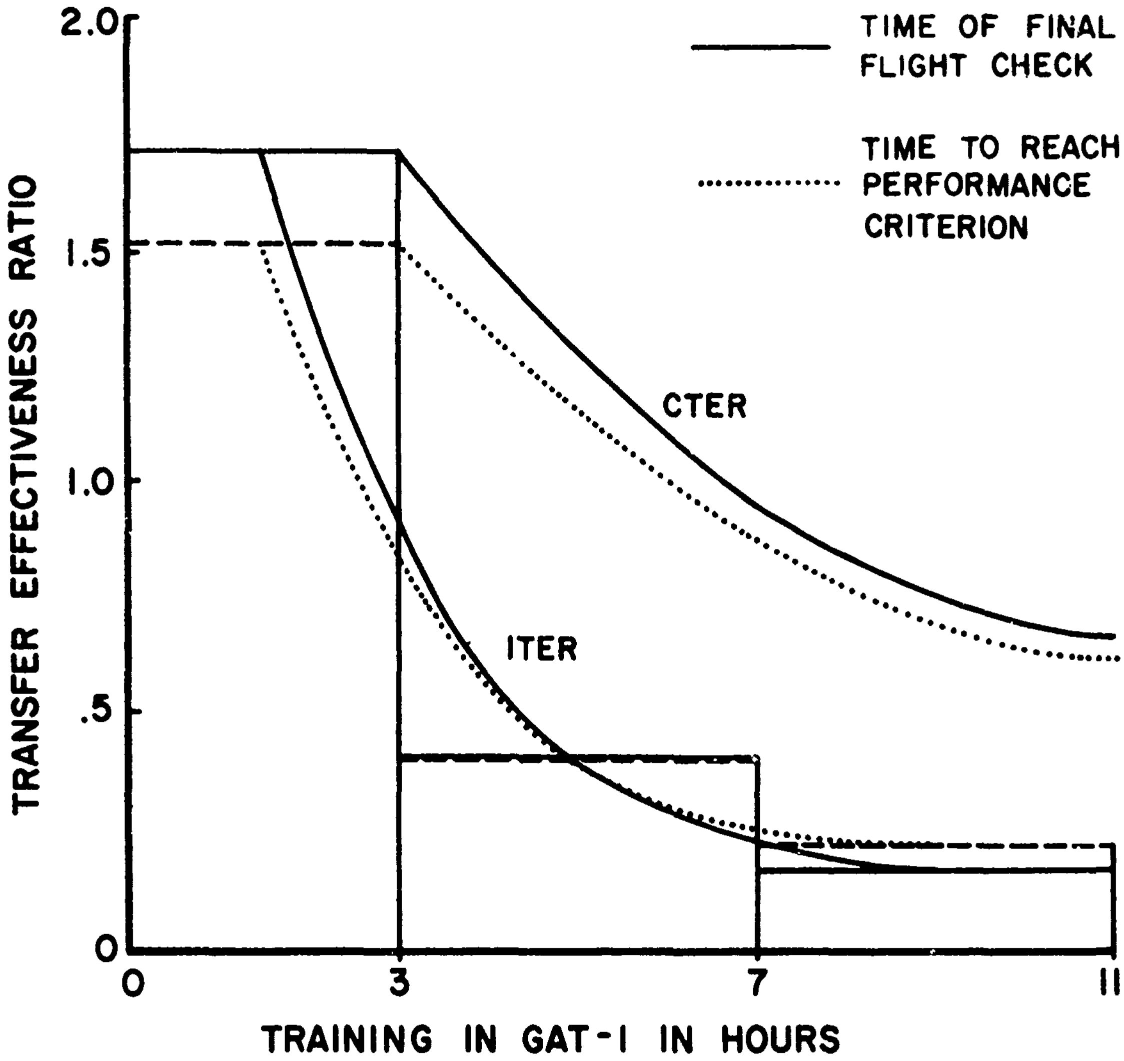

Figure 3. Cumulative and incremental transfer effectiveness for the Link GAT-1 used in a routine primary flight training program.

paralleled the average times at which they passed their flight checks, ranging from 0.35 hour earlier for the 7-hour transfer group to 0.93 hour for the control group.

Despite the fact that the differences between groups in times to criterion were almost identical to the differences in times to pass flight checks, the former set of differences was less reliable ($\underline{p}$ = 0.291) as shown in Table 5. Because of practical limits on the times at which flight checks could be given, as discussed previously, between-student variability was constrained, thereby causing differences between groups to appear more reliable for that measure than for the relatively unconstrained performance criterion measure.

Considering the close agreement among the mean differences between groups for the two measures, there is little doubt that incremental transfer of the orderly, r   ely decelerated form shown in Figure 3 would occur repeatedly under similar ons.

DISCUSSION

The findings presented tend to support the notion that the Incremental Transfer Effectiveness of a ground-based flight trainer, when used in a well-defined flight course, is a negatively decelerated function of the amount of ground-training given. A similar functional relationship would be expected to obtain between any two comparable training situations (Roscoe, 1971).

The Incremental Transfer Effectiveness Function plotted in Figure 3 allows a determination of the point at which ground training in the GAT-1 becomes uneconomical considering its hourly cost and that of the Cherokee airplane. Based on an hourly cost of $16 for GAT-1 instruction ($8 for the GAT-1 and $8 for the instructor) and $22 for the Cherokee ($14 and $8), ground training could be continued profitably until the next hour would save less than 16/22 or 0.73 hour in flight. Referring to Figure 3, that point occurred between the fourth and fifth hours of ground instruction in this experiment.

TABLE 4

Summary of Analysis of Variance of Times at Which Successful Members of the Four Groups Passed Their Final Flight Checks

Source of Variance	*df*	*MS*	*F*	*p*
Hours in GAT-1 (G: 0, 3, 7, 11)	3	141.97	6.19	0.0014
Subjects/Groups	42	22.93		
	45			

TABLE 5

Summary of Analysis of Variance of Times at Which Successful Members of the Four Groups Reached the Private Pilot Performance Criterion

Source of Variance	df	MS	F	p
Hours in GAT-1 (G: 0, 3, 7, 11)	3	124.82	1.29	0.2914
Subjects/Groups	42	96.95		
	45			

An item of passing interest is a comparison of the performance of the 11-hour transfer group in this experiment with that of its counterpart in a related experiment conducted by the same investigators in 1969 (Povenmire and Roscoe, 1971). The successful students in the group that received 11 hours in the GAT-1 in 1969 reached the criterion of Private Pilot proficiency for that study in an average of 34.5 hours (a saving of 11.0 hours); the group in 1972 required an average of 37.3 hours (a saving of 7.2 hours) to reach a new but evidently comparable criterion in view of the closely similar performances of the control groups in the two studies (45.4 versus 44.5 hours, respectively).

Although the between-student variability for the two groups was such that the mean differences between groups could easily have occurred by chance (evident by inspection), there is observational evidence that the GAT-1 was, in fact, less effective in 1972 than in 1969.

In 1969, the GAT-1 was new, as were most of the flight instructors. (Seven of the 16 had less than 100 hours of instructing experience each and only one had more than 500 hours.) The instructors liked the GAT-1, in comparison with the three AN-T-18s still in use, were tolerant of the GAT-1's reliability problems, and presented it to their students with enthusiasm.

By 1972, 15 of the 26 flight instructors who participated in the second experiment had at least two and one-half years of instructing experience during which the five GAT-1s used in the 1972 experiment had been the standard ground trainers for the Private Pilot course. Only four instructors had less than one year's experience using the GAT-1s. The new trainers' novelty and the instructors' patience with their frequently crippled condition had both diminished, and it is not difficult to believe that these factors could adversely affect the trainers' transfer effectiveness.

Additional differences in the use of the GAT-1s in the 1969 and 1972 studies warrant mention. The 1969 experiment was conducted during the eight-week summer session from mid-June to mid-August; the 1972 experiment was conducted during the 16-week fall and winter semester from mid-September through January.

In the spring, the flying weather in Illinois tends to be bad at the outset and to improve gradually thereafter; the summer thunderstorms tend to be more uniformly distributed; in the fall, flying conditions are delightful save for an occasional unseasonable snowstorm about the time of the Michigan game; in the winter, the weather is bad.

As a consequence, flight instructors tend to use up their students' allotted ground training early in the spring semester, to distribute it more evenly in summer, and to use it sparingly during the early fall when flying is such a delight, saving it for the bad days ahead. During the fall and winter semester, students often receive much of their ground training after having completed most of their dual flight instruction.

Because the transfer effectiveness ratios for various flight maneuvers and procedures vary (Flexman, Roscoe, Williams, and Williges, 1972), and because the transfer effectiveness for each item must be a decaying function of time, optimum utilization of a ground-based trainer is achieved when the time available is applied at those points at which it will do the most good and not whenever the field is closed. The use of a ground-based trainer in less than the optimum manner is an inevitable consequence of a calendar-limited flight course. If the instructor must choose between using a ground-based trainer inefficiently and wasting a flight period, he must surely choose the former.

In an ideal training situation, both the ground-based trainer and the airplane would always be available, and the instructor could deploy the one that would benefit the student more at the moment. In less than ideal situations, there is a premium on optimizing both the devices used and the manner in which they are used. The effectiveness of a ground-based flight trainer depends not only upon its degree and fidelity of simulation but also upon its trouble-free operation, the ingenuity of the flight instructor using it, and the confidence that all of these instill in the student.

ACKNOWLEDGMENTS

This research was supported by the Air Force Office of Scientific Research under Contract F44620-70-C-0105, "Enhancement of Human Effectiveness in System Design, Training, and Operation," monitored by Dr. Glen Finch, Program Manager, Life Sciences Directorate. This work is an outgrowth of a research project initiated in 1969 with the support of the Link Foundation. Individuals contributing notably to this effort include:

Omer Benn, Chief of Pilot Training, Institute of Aviation, for his participation in planning, organizing, and directing the experimental pilot training.

Flight instructors Harry R. Anderson, Kenneth R. Becher, Robert L. Bedows, Gregory S. Bettis, George B. Clark, Gregory N. Dohrn, David A. Domino, Thomas W. Emanuel, Richard N. Fried, Thomas H. Gordon, Kenneth R. Hamburger, James B. Jamison, Jeffrey A. Johnson, Stephen W. Koontz, David A. Lombardo, Earl Y. Lucas, Craig L. Mussman, Stephen F. Owen, Walter C. Peucker, Charles R. Pirnat, Ted Sigtenhorst, Gerald R. Spittler, Curtis W. Treichel, John F. Wick, Connie R. Younger, and flight instructor-observers Robert E. Adam, Kenneth R. Becher, Robert L. Bedows, James D. Erion, Steven L. Jenisio, David A. Lombardo, Steven J. Lorenzi, Richard M. Marinangel, Charles F. McGee, Craig L. Mussman, Walter C. Peucker, James R. Roombos, Bruce A. Shook, Barry A. Slingerland, Michael R. Sutton, Stephen L. Swofford, and Ricky A. Weinberg for their participation in the conduct of the experiment.

Undergraduate flight assistant Bruce A. Shook for training the flight instructors and the flight instructor-observers in standardized procedures for administration of the Illinois Private Pilot Performance Scale and for scheduling flight instructor-observers for all check flights.

Graduate Research Assistant Stanley R. Trollip for his development of the modified z-scoring procedures.

Professor Charles L. Hulin and Assistant Professor Kenneth M. Alvares for their consultation on questions of methodology.

Beverly H. Williges for her editorial hand holding.

And countless others, too numerous to mention, for their invaluable support.

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BIOGRAPHY

H. KINGSLEY POVENMIRE (The Incremental Transfer Effectiveness of a Ground-Based General Aviation Trainer) is a Research Associate and the head of the Flight Operations Group at the Aviation Research Laboratory of the Institute of Aviation, University of Illinois, Savoy, Illinois. Prior to joining the research staff, he was a flight instructor at the University of Illinois for three years. In September 1968, he was appointed supervisor of the basic flight group. He received his B.A. from San Diego State College in 1960 and his M.S. in Education from the University of Illincis in 1972. He has participated in several previous experimental programs utilizing the GAT-1 trainer for both private and instrument pilot training. He is currently responsible for airborne flight operations associated with research projects including an evaluation of the frequency-separated display principle, reorganization of manual flight control dynamics, determination of essential visual cues for contact flight operation, assessment of the predictive validity of ground-based flight checks, and the further quantification of transfer effectiveness ratios for ground-based flight trainers.

BIOGRAPHY

STANLEY N. ROSCOE (The Incremental Transfer Effectiveness of a Ground-Based General Aviation Trainer), Associate Director for Research of the Institute of Aviation and Professor of Aviation, Aeronautical and Astronautical Engineering, and Psychology, University of Illinois at Urbana-Champaign. Ph.D., experimental (engineering) psychology, University of Illinois, 1950. From 1943 to 1946, pilot instructor and transport pilot, Army Air Corps. From 1946 to 1952, Research Assistant, Research Associate and Assistant Professor, Aviation Psychology Laboratory, University of Illinois.

In 1952 he joined Hughes Aircraft Company where he established a human factors research and development program. He was Manager of the Display Systems Department at the time of his return to the University of Illinois in 1969. His Aviation Research Laboratory at the University Airport now supports a human factors research staff of approximately 50, including about 25 graduate research assistants, who perform contract research for ONR, AFOSR, FAA, AFHRL, and the Link Foundation. He is a past President of the Human Factors Society (1960-1961) and was a Member of the Executive Council continuously between 1959 and 1971. In 1969 he was cited by the Radio Technical Commission for Aeronautics for his contributions to the advancement of airborne area navigation.